

Frequency Analysis of Annual one Day Maximum Rainfall at Kassala State, Sudan

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Abstract:

Rainfall is the main driving force in the hydrology of arid and semi-arid regions. The hydrological data in arid and semiarid regions is lack due to the absent of field measurement and scarcity of data. The hydraulic design and management of water systems are not based on the long-term average of rainfall records but on particular rainfall depths that can be expected for a specific probability or return period. These rainfall depths can only be obtained by a thorough analysis of long time series of historic rainfall data. The most common approach for determining design storm events is frequency analysis. The aim of this paper is to conduct frequency analysis of annual daily maximum rainfall data for five stations in Kassala State using Hyfran-Plus software. Frequency rainfall analysis showed that the Log person type 3, Person type 3, Three-Parameter Log Normal, Three-Parameter Log Normal and Normal distributions provided the best-fit probability distribution at Aroma, Kassala, Mekali, Goz Rigab and Halfa EL Gadeeda rainfall gauging stations respectively. The analysis has shown that the maximum daily rainfall record about 118 mm in Aroma station. The maximum daily rainfall with a return period 50 year is about 103 mm in Kassala station.

Keywords: *frequency analysis, rainfall, arid and semiarid, Hyfran-Plus.*

تحليل ترددي لأقصى معدل هطول أمطار سنوي ليوم واحد في ولاية كسلا، السودان

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المستخلص

الأمطار هي من اهم البيانات الرئيسية في علم الهيدرولوجيا وخاصة في المناطق القاحلة وشبه القاحلة حيث يوجد نقص في البيانات الهيدرولوجية بسبب قلة القياس وندرة البيانات. لا يعتمد التصميم الهيدروليكي وإدارة مصادر المياه على متوسط قيم الامطار او القيمة القصوى المسجلة لفترة طويلة ولكن على قيمة امطار تصميمية معينة يمكن توقعها لاحتمال محدد أو زمن عودة محدد. لا يمكن الحصول على هذه القيمة التصميمية إلا من خلال اجراء تحليل شامل للسلاسل الزمنية الطويلة من بيانات هطول الأمطار المسجلة. الطريقة الأكثر شيوعاً لاجاد قيمة الامطار التصميمية هي تحليل التردد. الهدف من هذه الورقة هو إجراء تحليل ترددي لبيانات الامطار اليومية القصوى خلال السنة لخمس محطات في ولاية كسلا باستخدام برنامج Hyfran-Plus. أظهر نتائج تحليل التردد للامطار أن التوزيعات الاحتمالية المناسبة هي توزيع بيرسون النوع 3، توزيع بيرسون اللوغريثمي للنوع 3، توزيع اللوغريثمي الطبيعي (3 معاملات)، توزيع اللوغريثمي الطبيعي (3 معاملات) و التوزيع الطبيعي لكل من محطات القياس (أروما، كسلا، مكالي، قوز رجب وحلفا الجديدة) على التوالي. وأظهر التحليل ايضاً أن قيمة الامطار القصوى اليومية المسجلة خلال السنة في المنطقة هي حوالي 118 ملم في محطة أروما. والقيمة التصميمية للامطار القصوى اليومية لزمن عودة 50 سنة هي حوالي 103 ملم في محطة كسلا.

الكلمات المفتاحية: تحليل الترددات، هطول الأمطار، المناطق القاحلة وشبه القاحلة، هيفران بلس.

Introduction:

Rainfall is the main driving force in the hydrology of arid and semi-arid regions. It is commonly subjected to sporadic storms that vary greatly in time and space. Particularly where the rain gauge network is sparse or absent. The hydraulic design and management of water systems are not based on the long-term average of rainfall records but on particular rainfall depths that can be expected for a specific probability or return period. These rainfall depths can only be obtained by a thorough analysis of long time series of historic rainfall data. The most common approach for determining design storm events is frequency analysis (WMO 1990). Frequency analysis is used to predict how often certain values of a variable phenomenon may occur and to assess the reliability of the prediction. It is a statistical technique to estimate rainfall depths that can be expected for selected probabilities or return periods. The estimates are required for determining design rainfalls and design discharges for the hydraulic design and management.

Fitting a distribution to data sets provides a compact and smoothed representation of the frequency distribution revealed by the available data, and leads to a systematic procedure for extrapolation to frequencies beyond the range of the data set. When rainfall variables are well-described by some family of distributions, a task for the hydrologist is to estimate the parameters of that distribution so that required quantities and expectations can be calculated with the "fitted" model. Appropriate choices for distribution functions can be based on examination of the data using probability plots and moment ratios, the physical origins of the data, previous experience, and administrative guidelines. Different methods and software of frequency analysis are available.

Several general approaches are available for estimating the parameters of a distribution. A simple approach is the method of moments (developed by Karl Pearson in 1902), which uses the available sample to compute an estimate parameters so that the theoretical moments of the distribution of X exactly equal the corresponding sample moments. Alternatively, still another method that has strong statistical motivation is the method of maximum likelihood (developed by R.A. Fisher in 1922). Maximum likelihood estimators (MLEs) have very good statistical properties in large samples, and experience has shown that they generally do well with records available in hydrology. However, often MLEs cannot be reduced to simple formulas, so estimates must be calculated using numerical methods (Kite, 1988). MLEs sometimes perform poorly when the distribution of the observations deviates in significant ways from the distribution being fit.

In hydrological research, maximum precipitation is usually determined utilizing lognormal distribution, normal distribution, Pearson type 3, exponential function, generalized distribution of extreme value (GEV), Gumbel distribution, Pareto and Weibull distribution (Amin *et al.* 2016). This paper aim to conduct frequency analysis of annual daily maximum rainfall data for five stations in Kassala State has been carried out to be used by researchers, hydrologists and design engineers for the design of hydraulic structures within study area.

Study Area:

Kassala state is located in eastern Sudan and lies between latitudes 14.45 and 17.15 north and longitudes 34.40 and 37 east. It has international borders with Ethiopia and Eritrea in the east, and national borders with Red Sea state in the north, River Nile state and Khartoum states in the north-west and Gedaref state in the southwest. The total area of the state is 52,949 square kilometers, which represent 2.25 per cent of the total area of Sudan with population density of 47.6 persons per square kilometer. Administratively, Kassala state is divided into eleven localities (Atbara River, Hamashkoreeb, Kassala Town, New Halfa, North Delta, Rural Aroma, Rural Kassala, Seteet, Wad El Helew, West Kassala, Telkok). As many parts of Sudan, the climate in Kassala is semi-tropical. The rainfall rate ranges between 104 millimeters in Kassala city, and 300 millimeters at Wad el Helew locality. Almost every year, Kassala state is struck by natural disasters, including floods, droughts and subsequent desertification (UNICEF, 2022). Table1 shows locations of rainfall stations in the study area. Fig1 and table1 show the location map of the study area and rainfall station.

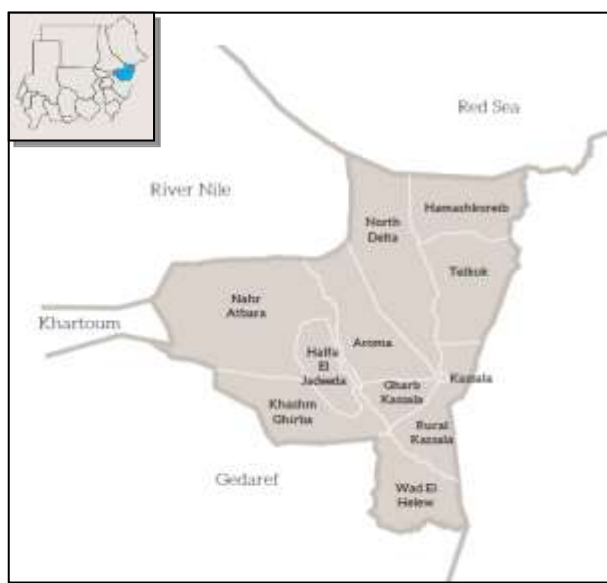


Figure 1: Location Map of the study area (UNICEF, 2022)

Table (1) Rainfall Stations in the Study Area

| Stations | Start | End | N.O of years | E | N |
|------------------|-------|------|--------------|-------|----------|
| AROMA | 1927 | 1991 | 62 | 36.15 | 15.83333 |
| KASSALA | 1907 | 2000 | 92 | 36.4 | 15.46667 |
| MEKALI | 1939 | 1979 | 34 | 36.3 | 15.73333 |
| GOZ RIGAB | 1944 | 1979 | 32 | 35.5 | 16.025 |
| HALFA EL GADEEDA | 1970 | 2000 | 31 | 35.6 | 15.31667 |

Frequency Analysis of the Annual Daily Maximum Rainfall:

The first step in frequency analysis is to obtain the annual daily maximum values of rainfall from historical records of selected stations to carry out frequency analysis using the software package Hyfran-Plus.

The Hyfran-Plus is software package used to fit statistical distribution. It includes a number of mathematical tools that can be used for statistical analysis of extreme events. It provides the verification of statistical hypothesis for independence and homogeneity, supports a large number of statistical probability distributions and several fitting methods. Hyfran-Plus also includes support for goodness-of-fit tests and information criterion tests for distribution ranking (AMEC-EIC, 2014).

The daily maximum rainfall data were analyzed for the stations. The following six statistical distributions were used (Normal (N), Distribution, Two-Parameter Log Normal (LN II)distribution, Three-Parameter Log Normal (LN III)distribution, Person type 3 (P III)distribution, Log person type 3 (LP III), Distribution and Gumbel (Extreme Value Type I)distribution). Two methods of parameter estimation were also used namely Method of Moment (MM) and method of Maximum Likelihood (ML). Three goodness of fit criteria; namely, Kolmogorov Smirnov, Chi square and standard error; were used to judge and obtain the best distribution. Table (2) shows the basic statistical properties of annual maximum daily rainfall and the best distributions.

Table (2): Basic Statistical Properties and the Best distributions

| Stations | No of years | Statistical Parameter | | | | Max in Record | Fitted Dist. | Analysis Method |
|-----------------|-------------|-----------------------|------|------|------|---------------|--------------|-----------------|
| | | Mean | S.D | C.V | S.E | | | |
| Aroma | 61 | 43.32 | 17.1 | 0.4 | 2.18 | 118 | LP III | MM |
| Kassala | 92 | 51.38 | 20.1 | 0.39 | 2.1 | 107 | PIII | ML |
| Mekali | 32 | 43.91 | 16.3 | 0.37 | 2.81 | 83 | LN III | ML |
| Goz Rigab | 32 | 29.38 | 15.3 | 0.52 | 2.71 | 70 | LN III | ML |
| Halfa ELGadeeda | 30 | 49.1 | 22.4 | 0.47 | 4.12 | 100 | N | MM |

Accordingly, the maximum daily rainfall depth for selected return periods (5, 10, 25, 50, 75, 100 and 150years) were determined. The results are shown in Table 3.

Table (3): Daily Maximum Observed Rainfall with various Return Periods

| Stations/ Return Periods | 5 | 10 | 25 | 50 | 75 | 100 | 150 |
|--------------------------|-----------|-----------|-----------|------------|------------|------------|------------|
| Aroma | 55 | 65 | 79 | 89 | 96 | 101 | 108 |
| Kassala | 67 | 78 | 93 | 103 | 109 | 113 | 119 |
| Mekali | 57 | 66 | 78 | 87 | 91 | 95 | 100 |
| Goz Rigab | 42 | 50 | 59 | 65 | 69 | 71 | 74 |
| Halfa EL Gadeeda | 68 | 79 | 89 | 96 | 100 | 102 | 106 |
| Maximum | 68 | 79 | 93 | 103 | 109 | 113 | 119 |

Conclusion:

Frequency analysis of extreme rainfall events has scientific and practical value in the context of water resource management. Annual maximum rainfall data based on daily duration at five rainfall-gauging stations located in Kassala State were used in this study. The purpose of the study was to find the best-fit probability distribution at Kassala State rainfall gauging stations. The Log person type 3, Person type 3, Three-Parameter Log Normal, Three-Parameter Log Normal and Normal distributions provided the best-fit probability distribution at Aroma, Kassala, Mekali, Goz Rigab and Halfa EL Gadeeda rainfall gauging stations respectively. The expected values of designed rainfall using best-fit distribution with different return periods of 25, 50, 75, 100 and 150 years were determined. The analysis has shown that the maximum daily rainfall record about 118 mm in Aroma station. The maximum daily rainfall with a return period 50 year is about 103 mm in Kassala station.

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